High-power Yb- and Tm-doped double tungstate channel waveguide lasers

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The potassium double tungstates $KGd(WO_4)_2$, $KY(WO_4)_2$, and $KLu(WO_4)_2$ are excellent candidates for solid-state lasers [1] because of their high refractive index of ~2.0-2.1, the large transition cross-sections of rare-earth (RE^{3+}) ions doped into these hosts, and a reasonably large thermal conductivity of ~3.3 W m^{-1} K^{-1}. Exploiting these advantages, Yb- [2] and Tm-doped [3] $KY(WO_4)_2$ planar waveguide lasers were demonstrated. Co-doping of $KY(WO_4)_2$:RE^{3+} thin films with Gd^{3+} and Lu^{3+} ions provides lattice matching and enhanced refractive index contrast of up to 7.5×10^{-3} with respect to the $KY(WO_4)_2$ substrate, thus thinner waveguides with better mode confinement [4], enabling highly efficient planar waveguide lasers [5] and facilitating microstructuring.

We grew $KY_{1-x-y}Gd_xLu_y(WO_4)_2$:$RE^{3+}$ layers with various compositions onto undoped $KY(WO_4)_2$ by liquid phase epitaxy. Replacing Y^{3+} in the layer completely by Gd^{3+} and Lu^{3+} ions results in layers with a refractive-index contrast of $>2 \times 10^{-2}$. Channel waveguides were microstructured into the layers by Ar^+ beam etching [6]. The excellent pump and signal mode confinement in these channel waveguides, combined with the aforementioned attractive properties of the host material, resulted in highly efficient lasers.

In $KGd_{0.49}Lu_{0.485}Yb_{0.025}(WO_4)_2$ channel waveguides with ~0.34 dB/cm propagation loss at 1.0 µm, channel waveguide lasers with butt-coupled mirrors delivered 418 mW of output power at 1023 nm with a slope efficiency of 71% (Fig. 1). By pumping at 973 nm and lasing at 980 nm, a record-low quantum defect of 0.7% was achieved [7]. 4-µm-deep Bragg gratings were etched by focused ion beam (FIB) milling. An on-chip integrated laser cavity was formed by this distributed Bragg reflector and a FIB-polished waveguide end-facet (Fig. 2) and the first on-chip integrated double tungstate waveguide laser at 980 nm was demonstrated [8].

In $KY_{0.4}Gd_{0.295}Lu_{0.29}Tm_{0.015}(WO_4)_2$ channel waveguides with ~0.11 dB/cm propagation loss at 1.9 µm, laser experiments with butt-coupled mirrors demonstrated an output power of 149 mW and slope efficiency of 31.5% when pumping at 794 nm in TM polarization (Fig. 3). The lowest threshold was 7 mW. The laser wavelength shifted from 1930 nm via 1906 nm to 1846 nm with increasing outcoupling degree [9].

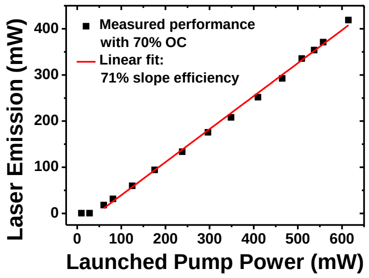

Fig. 1. Input-output curve of a $KGd_{0.49}Lu_{0.485}Yb_{0.025}(WO_4)_2$ channel waveguide laser at 1023 nm, pumped at 981 nm.

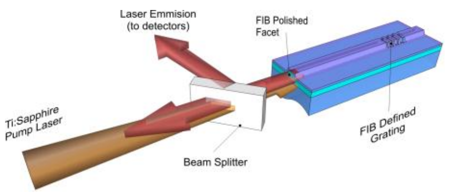

Fig. 2. An integrated laser with a distributed Bragg reflector cavity in a channel waveguide of $KGd_{0.49}Lu_{0.485}Yb_{0.025}(WO_4)_2$.

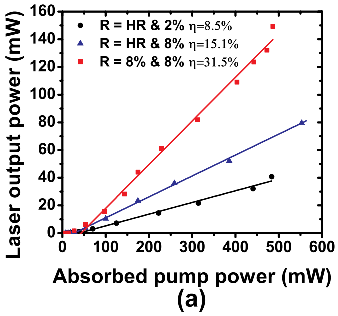

Fig. 3. Input-output curve of a $KY_{0.4}Gd_{0.295}Lu_{0.29}Tm_{0.015}(WO_4)_2$ at 1.9 µm, pumped at 794 nm.

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